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Hearing protectors, safety glasses and respiratory protective equipment in combination: Effect on sound attenuation

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November 2001

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Canada

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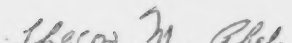

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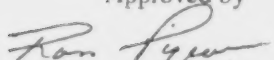

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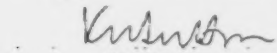

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Abstract

This study assessed the effect of other safety gear worn in combination on the attenuation afforded by earmuffs attached to a hard hat.

Seventy-two males and females participated· 24 under the age of 40 years with normal-hearing, and 48 over the age of 40 years, half with normal hearing and half with bilateral high-tone hearing loss. Measurements made with the ears unoccluded, with the muffs alone, and with the muffs in combination with safety glasses, an air-purifying half mask respirator or both glasses and respirator included (1) diffuse field hearing thresholds from 0.25-8 kHz, and (2) consonant discrimination in quiet and in speech spectrum noise. Attenuation was derived by subtracting the unoccluded from the protected threshold.

Muff attenuation was within 6 dB of the manufacturer's specifications but decreased by as much as 5 dB when the glasses or respirator were worn and by 9 dB with both these devices. Males achieved 3 dB higher attenuation than females. Hearing status had no effect Consonant discrimination was significantly poorer in noise. The impaired performed more poorly when protected but there was no difference due to combination.

The results demonstrated that hearing protector attenuation may be compromised when are safety gear are worn in combination. In individuals with pre-existing hearing loss, the use of hearing protectors may increase communication handicap.

Résumé

La présente étude visait à déterminer si l'atténuation du bruit au moyen de protecteurs auditifs fixés à un casque de sécurité est compromise par le port d'autres dispositifs de protection.

Soixante-douze hommes et femmes ont participé à l'étude : 24 de moins de 40 ans ayant une acuité auditive normale, et 48 de plus de 40 ans dont la moitié avaient une acuité auditive normale et l'autre moitié une déficience auditive bilatérale aux fréquences élevées. Des mesures effectuées sans les protecteurs auditifs, avec les protecteurs auditifs seuls, et avec les protecteurs auditifs combinés à des lunettes protectrices, combinés à un demi-masque d'épuration d'air puis combinés à ces deux dispositifs, ont porté (1) sur les seuils d'audibilité en champ diffus entre 0,25 et 8 kHz et (2) sur la discrimination des consonnes en l'absence de bruit, et avec bruit aux fréquences vocales. On a calculé l'atténuation en soustrayant du seuil avec protection le seuil d'audibilité sans protection.

L'atténuation obtenue se situait dans une marge de 6 dB par rapport aux spécifications du fabricant, mais était réduite d'une valeur pouvant atteindre 5 dB lorsque le sujet portait les lunettes ou le demi-masque, et 9 dB lorsqu'il portait les deux dispositifs. L'atténuation était supérieure de 3 dB pour le groupe d'hommes. L'état auditif n'a eu aucun effet. La discrimination des consonnes diminuait sensiblement sur fond de bruit. Les malentendants entendaient moins bien avec les protecteurs auditifs, mais la combinaison des autres dispositifs n'a eu sur eux aucune influence.

Les résultats ont montré que l'atténuation au moyen de protecteurs auditifs peut être compromise par le port simultané d'autres dispositifs protecteurs Chez les personnes malentendantes, l'utilisation de protecteurs auditifs pourrait accroître leur handicap auditif.

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Executive summary

This study was designed to determine whether the sound attenuation afforded by hearing protective earmuffs would be compromised by the wearing of other safety gear in combination, in close proximity to the head. Seventy-two working-aged subjects (36 males and 36 females) were tested. Each gender group comprised 12 subjects with normal hearing, under the age of 40 years, and 24 subjects who were 40 years of age or older, 12 with normal hearing and 12 with moderate bilateral high-tone sensorineural hearing loss, characteristic of the damaging effects of noise exposure. Each subject was tested with the ears unoccluded and protected with Class A earmuffs (CSA Z94.2-94) mounted on a hard hat.

Measurements were made with the muffs on hard hat worn alone, and with the muffs on hard hat worn in combination with commonly used safety glasses, an air-purifying half-mask respirator or both the glasses and respirator. For each of the five ear conditions, free-field hearing thresholds were determined, in quiet, for eight one-third octave noise bands centred at 0.25, 0.5, 1, 2, 3.15, 4, 6.3 and 8 kHz, using a threshold tracking procedure. In accordance with the real-ear at threshold (REAT) method (ANSI S12.6-1984), sound attenuation was derived by subtracting the unoccluded from the occluded threshold at each frequency, for each of the four protected conditions. Measurements were also made, within each of the unoccluded and protected conditions, of consonant discrimination in quiet and in a background of speech spectrum noise (S/N = -5 dB).

The results showed that for each of the protected conditions, the attenuation afforded by the muff increased linearly from 0.25 kHz to 1 kHz, and then remained fairly stable. The greatest attenuation was achieved with the muff on hard hat worn alone, and the least attenuation, with the muff on hard hat in combination with the safety glasses and respirator. The difference was greatest (9 dB) at 0.25 and 0.5 kHz. Across listening conditions and stimulus frequencies, females achieved 3 dB less attenuation than males. The signal detection measurements indicated that the hearing-impaired listeners were disadvantaged by the wearing of the muffs. At frequencies above 2 kHz, their protected thresholds were greater than 55 dB SPL. All subjects showed significantly poorer consonant discrimination in noise than in quiet. The decrement was greater for the hearing-impaired. The wearing of safety gear had no effect for the normal-hearing listeners. In the impaired group, the protected scores were 23% lower. However, there was no additional effect of protector combination.

These results underscore the potential for reducing the beneficial effects of hearing protective earmuffs when they are worn in combination with other safety gear. They also provide strong evidence that, in individuals with pre-existing hearing loss, the use of hearing protective devices may increase hearing handicap.

Abel, S.M, Sass-Kortsak, A. and Kielar, A. 2001. Hearing protectors, safety glasses and respiratory protective equipment in combination: effect on sound attenuation. DCIEM TR 2001-140. Defence and Civil Institute of Environmental Medicine.

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Sommaire

La présente étude visait à déterminer si l'atténuation du bruit au moyen de protecteurs auditifs est compromise par le port d'autres dispositifs de protection très près de la tête. Soixante-douze sujets en âge de travailler (36 hommes et 36 femmes) ont été testés. Chacun des deux groupes comprenait 12 sujets de moins de 40 ans ayant une acuité auditive normale et 24 sujets de 40 ans et plus dont 12 avaient une acuité auditive normale et 12 présentaient une déficience auditive sensorineuronale bilatérale modérée aux fréquences élevées, caractéristique des effets nocifs d'une exposition au bruit. Chaque sujet a été testé sans protection auditive et avec des protecteurs auditifs de classe A (CSA Z94.2-94) fixés à un casque de sécurité.

Des mesures ont été effectuées sur les sujets lorsqu'ils portaient seulement les protecteurs auditifs fixés à un casque de sécurité, puis lorsqu'ils portaient les protecteurs auditifs fixés à un casque de sécurité avec des lunettes protectrices ordinaires, avec un demi-masque d'épuration d'air, ou avec ces deux dispositifs. Pour chacune des cinq conditions d'audition, les seuils d'audibilité en champ libre ont été déterminés en l'absence de bruit, suivant une procédure de détermination de seuil pour huit bandes de bruit de tiers d'octave centrées sur les fréquences de 0,25 kHz, 0,5 kHz, 1 kHz, 2 kHz, 3,15 kHz, 4 kHz, 6,3 kHz et 8 kHz. Suivant la méthode REAT (« Real-ear at threshold », ANSI S12.6-1984), on a calculé l'atténuation acoustique en soustrayant du seuil d'audibilité avec occlusion le seuil d'audibilité sans occlusion, cela pour chaque fréquence et chacune des quatre conditions de protection. De plus, des mesures de la discrimination des consonnes aux fréquences vocales (S/B = -5 dB) en l'absence de bruit, et sur fond de bruit aux fréquences vocales, ont été effectuées pour chacune des conditions de protection et de non-protection.

Les résultats ont montré que, pour chacune des conditions de protection, l'atténuation résultant de la protection augmentait de façon linéaire de 0,25 kHz à 1 kHz, puis demeurait assez stable. La plus forte atténuation a été obtenue avec les protecteurs auditifs fixés à un casque de sécurité seuls, et la plus faible avec les protecteurs auditifs fixés à un casque de sécurité portés conjointement avec les lunettes protectrices et le demi-masque. La différence était la plus marquée (9 dB) à 0,25 et à 0.5 kHz. Pour l'ensemble des conditions d'écoute et des fréquences stimuli, l'atténuation était inférieure de 3 dB chez les femmes. Les mesures de détection des signaux ont indiqué que le port des protecteurs auditifs désavantageait les sujets malentendants. Aux fréquences supérieures à 2 kHz, leurs seuils avec protection dépassaient un niveau sonore de 55 dB. La discrimination des consonnes étaient sensiblement plus faible sur fond de bruit qu'en l'absence de bruit pour tous les sujets, et particulièrement dans le cas des malentendants. Le port des dispositifs protecteurs additionnels n'a pas eu d'effet sur les sujets ayant une acuité auditive normale, mais on a constaté un écart négatif de l'ordre de 23 % pour les malentendants. Toutefois, la combinaison des dispositifs protecteurs ne comportait pas d'effet additionnel.

Ces résultats montrent que les protecteurs auditifs pourraient être moins efficaces lorsqu'ils sont portés avec d'autres dispositifs protecteurs. De plus, les résultats indiquent fortement que l'utilisation de protecteurs auditifs pourrait accroître le handicap auditif des personnes malentendantes.

Abel, S.M, Sass-Kortsak, A. and Kielar, A. 2001. Hearing protectors, safety glasses and respiratory protective equipment in combination: effect on sound attenuation. DCIEM TR 2001-140. Defence and Civil Institute of Environmental Medicine.

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Introduction

Personal hearing protectors have been in common usage for the past forty years (Abel and Haythornthwaite, 1984). They provide an easily-implemented, effective, and low-cost method of minimizing the risk of hearing loss associated with exposure to high-level noise (Savell and Toothman, 1987; Brühl et al., 1994). Unfortunately, the attenuation actually achieved by the user generally falls short of the manufacturers' specifications. Specifications are typically based on optimal fitting of the device by trained personnel. Lesser observed "real-world" values are largely due to poor fitting by the user which may preclude an air tight seal of the device with the ear but may also result from inadequate maintenance of the device, incorrect sizing, slack headband tension, and incompatibility with other protective gear (Riko and Alberti, 1982; Abel et al., 1982; Abel and Rokas, 1986; Abel et al., 1988; Berger, 1988; Berger and Mitchell, 1989; Abel et al., 1990; Berger and Lindgren, 1992; Berger et al., 1996). The issue of poor fit is further addressed in the newly revised American National Standard on hearing protection (ANSI S12 6-1997).

Pre-existing hearing loss will not affect the amount of sound reduction achieved by the user, although it may affect his/her protected communication capability (Abel et al., 1985). The device attenuates the incoming signal, and coupled with elevated hearing thresholds, could prove detrimental to auditory perception. Gender is also a significant determinant of outcome. In a study by Abel et al. (1988), the sound attenuation achieved by men and women was measured for four different earplugs, only two which were available in more than one size. The results showed that the mean attenuation observed in women was significantly less than that for men for devices available in one size. In a subsequent study, Abel et al. (1990) demonstrated that the attenuation realized within subject was related to the cross-sectional area of the ear canal. Cross-sectional area was significantly less in women. The smaller the canal, the poorer the fit, and the less the attenuation achieved. Poor fit is not confined to plugs. Women may also experience problems with earmuffs, due to inadequate sizing of the ear cup, headband or hard hat attachments (Abel and Giguère, 1997).

A potential drawback associated with hearing protector utilization is interference with the performance of auditory tasks. These include the detection, discrimination and localization of auditory warning signals, and speech communication. Sounds may be more difficult to perceive and distinguish, and if perceptible, possibly distorted, as a result of alterations of temporal and spectral features due to the physical features of the device and its attenuation characteristic (Casali, 1989; Abel, 1995). The extent to which these factors will affect performance may further depend on the characteristics of the listener--her/his hearing acuity, age and fluency with the test language, as well as the presence of background sounds and reverberation of the listening environment (Abel, 1995). The general consensus from the laboratory studies conducted to date is that in normal-hearing listeners, the detection of auditory signals in noise backgrounds will not be negatively affected by the wearing of hearing protective devices (Wilkins and Martin, 1981; Wilkins and Martin, 1987). Indeed, there is evidence that thresholds may decrease (i.e., hearing may improve) by 3-6 dB (Wilkins and Martin, 1977; Abel et al., 1985; Wilkins and Martin, 1987; Letowski and McGee, 1993). In contrast, hearing-impaired listeners may be disadvantaged, if the attenuated signal is below threshold (Forshaw, 1977; Abel et al , 1985; Robinson and Casali, 1995).

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As in the case of signal detection, the effect of hearing protective devices on speech understanding is critically dependent on the hearing status of the individual (Bauman and Marston, 1986; Wilde and Humes, 1990). Abel et al (1982) studied the ability of subjects with normal hearing and bilateral sensorineural hearing loss, either fluent or non-fluent in English, to correctly repeat monosyllabic English words. Listeners were tested with the ears unoccluded or fitted with various conventional muffs and plugs. For both groups, scores were higher for speech presented in quiet than when mixed with either white noise or crowd noise, presented at 85 dBA. Performance decreased with a decrease in the speech-to-noise (S/N) ratio and was worse in the crowd noise. In the normal listeners, unoccluded and protected performance were no different. In contrast, for the hearing-impaired group, the protectors resulted in a significant decrement. Non-fluency with the language spoken did not interact with hearing loss. For both groups, non-fluency resulted in a decrement in performance of 10% to 20% across the various ear by background listening conditions.

There is virtually no information in the literature on the effect on hearing protector attenuation of other safety equipment worn in combination (Ribera et al, 1996). The Canadian standard on hearing protection (CSA Z94.2-94) cautions that "the type of protector that best suits a person will depend upon other equipment he must wear (e.g., safety helmet, eyeglasses, and respirator)." The main concern is that the utilization of other devices worn in proximity to the head might interfere with the seal of the muff to the ear, thereby compromising its sound reduction capability. However, there is little objective documentation of this outcome. A recent study by Wagstaff et al. (1996) assessed understanding of digits and words in helicopter noise in young normal-hearing subjects fitted with a communication headset, with or without the addition of sunglasses. The noise was held constant at a level of 97 dBA, while the speech level was varied to achieve a wide range of speech-to-noise ratios. Performance with both types of speech materials was poorer when the glasses were worn. The authors argued that this effect was due to an enhanced masking effect from low-frequency noise leakage under the poorly sealed muff.

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Rationale

In today's industrial environments, safety devices are typically worn in combination. Current North American and international safety standards do not address the impact of the interaction which might prove detrimental to the performance of the various components. This research was designed to determine whether the sound attenuation afforded by hearing protective earmuffs would be compromised, if the device was worn in combination with other safety gear worn in close proximity to the head. Combined usage of such devices has the potential of compromising the seal between the muff and the outer ear, resulting in noise leakage under the earcup. The general objective of the research was to assess hearing thresholds and speech understanding in subjects wearing a Class A muff (CSA Z94.2-94) mounted on a hard hat, either worn alone or in combination with commonly used safety glasses and/or an air-purifying half-mask respirator, relative to unoccluded listening. The hearing threshold measurements were made over a broad range of sound frequencies normally considered in manufacturers' specifications for hearing protective devices. Sound attenuation at each frequency was derived by subtracting the observed unoccluded from the protected threshold values. Speech understanding in quiet and noise was also measured to assess possible changes in communication capability. Both males and females were tested to allow an assessment of gender differences in hearing protector effectiveness. Within each gender group, the results of young and middle-aged subgroups with normal and impaired hearing were compared to assess the implications for worker safety of age and pre-existing hearing loss.

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Methods and materials

Experimental design

Seventy-two working-aged adults (36 males and 36 females) were tested. Each gender group was comprised of 12 normal-hearing adults under the age of 40 years and 24 adults who were 40 years of age or older, 12 with normal hearing and 12 with moderate bilateral high-tone sensorineural hearing loss. Each subject was tested under five ear conditions: (1) UN-with the ears unoccluded, (2) M-with Class A muffs (Aearo Peltor H7P3E) attached to a hard hat (LR46 with 6 pt suspension), (3) MR-with the muffs on hard hat and an air-purifying half-mask respirator (MSA Comfo Classic with twin GMA air vapor filter cartridges), (4) MG-with the muffs on hard hat and safety glasses (Aearo Nassau Plus Eye Wear), and (5) MGR-with the muffs on hard hat, safety glasses and respirator. These devices were fitted by a trained technician. The unoccluded condition was presented first, followed by the four protected conditions in random order.

Within each ear condition, measurements were made of (1) diffuse-field hearing thresholds in quiet for eight one-third octave noise bands centred at frequencies from 0.25 kHz to 8 kHz, and (2) consonant discrimination in quiet and in a continuous background of 80 dB SPL speech spectrum noise. The presentation level, 5 dB below the requirement for hearing protector usage in the workplace (see CSA Z94.2-94), was chosen to ensure that subjects would not be at risk during unoccluded listening. The speech was fixed at a raised conversational level of 75 dB SPL, modelling real world scenarios (Gasaway, 1985). Attenuation was derived by subtracting the unoccluded from the occluded hearing threshold for each frequency, within each of the protected conditions.

Subjects

Subjects were recruited by posting notices throughout the University of Toronto. Colleagues in the Department of Otolaryngology advertised the study to their clinic patients with hearing loss. The study was open to men and women, 18-70 years of age, who were fluent in English. Previous research had demonstrated that non-fluency might confound the effect of noise on speech understanding in both normal and impaired listeners (Abel et al., 1982). Prospective candidates were screened by telephone for a history of head injury, systemic disease and neurological disorders to rule out central auditory processing deficits and to ensure a basic level of functioning necessary for the performance and completion of the experimental tasks.

Individuals under the age of 40 years were admitted to the study if their unoccluded diffuse-field hearing thresholds were less than 20 dB HL from 0.25-8 kHz. Individuals who were 40 years of age or older underwent a headphone hearing screening test prior to participation. Those with thresholds in both ears less than 25 dB HL at 0.5 and 4 kHz (Yantis, 1985) were admitted to the normal-hearing groups. Those with a clinical diagnosis of bilateral senorineural hearing loss and thresholds of 25-60 dB HL (worse ear) at 4 kHz and interaural differences no greater than 20 dB were admitted to the hearing-impaired groups. Summary statistics on the age of subjects in the six groups tested and head phone hearing thresholds for

subjects in the four older groups are presented in Tables 1 and 2. These data confirm that the inclusion criteria were met.

Head circumference, a possible determinant of the fit of the muff and thus the attenuation realized, was also measured in each participant. Summary statistics are presented in Table 3. On average, head circumference was 2 cm greater in males.

Apparatus

The psychoacoustic experiments were conducted in the Hearing Research Laboratory, Samuel Lunenfeld Research Institute of Mount Sinai Hospital, Toronto. The apparatus has been previously described in detail (Giguère and Abel, 1990). Subjects were tested individually within a semi-reverberant sound proof booth (3.5m by 2.7m by 2.3 m) that met the requirements for hearing protector testing specified in ANSI S12.6-1984. The ambient noise was less than the maximum permissible for audiometric test rooms specified in ANSI S3.1-1991. Pure-tone stimuli used for hearing screening were generated by a Hewlett Packard multifunction synthesizer (HP 8904A), and presented monaurally over a Telephonics TDH-49P headset. The one-third octave noise bands for the experimental hearing threshold task were generated using band pass filtered (Brŋel & Kjaer 1617) white noise from a noise generator (Brŋel & Kjaer 1405). The speech test was commercially available on audio cassette and was played by a Yamaha twin cassette deck (KX-W900/U), either in quiet or mixed with the pre-recorded speech spectrum noise. The one-third octave noise bands, speech materials and speech spectrum noise background were presented free-field over a set of three loudspeakers (Celestion DL10) positioned to create a uniform sound field. Stimulus selection and fine adjustment of stimulus level, duration and envelope shaping were accomplished by means of a Coulbourn Instruments modular system. The output was fed to a pair of manual range attenuators (HP 350D) and Rotel mixer amplifier (RA 1412). For the measurement of hearing thresholds, subjects signified their responses by means of a hand held push-button switch. Paper and pencil were used for the consonant discrimination task. Devices were controlled from a personal computer (AST Premium 286) via IEEE-488 and Lablinc interfaces, and digital I/O lines.

Procedure

Diffuse-field hearing thresholds were measured once for each of eight one-third octave noise bands, centred at frequencies ranging from 0.25kHz to 8 kHz for each of the five ear conditions. A variation of Bŏkŏsy tracking was used (Yantis, 1985) For each threshold determination, the stimulus was pulsed continuously at a rate of 2.5 per second. The pulse duration was 250 ms, including a rise/decay time of 50 ms. Subjects were instructed to depress an on/off push-button switch whenever the pulses were audible, and to release the switch when they could no longer be heard. The sound level of consecutive pulses was increased in steps of 1 dB until the switch was depressed and then decreased at the same rate of change until the switch was released. The tracking trial was terminated after a minimum of eight alternating intensity excursions with a range of 4 to 20 dB. Hearing threshold was defined as the average sound level of the eight final peaks and valleys.

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Speech understanding was investigated using the Four Alternative Auditory Feature Test (FAAF) of consonant discrimination developed by Foster and Haggard (1979). For each of the five ear conditions, the subject was given a typewritten list of 80 sets of four common monosyllabic words in the form of consonant-vowel-consonants. Half the sets, randomly throughout the list, contrasted the initial and half the final consonant (e g., wet, bet, get, yet OR bad, bag, bat, back). One word from each set was presented over the loudspeakers, and the subject was required to circle the alternative heard. The first half of each list was presented in quiet and the second half in continuous speech spectrum noise (S/N=-5 dB). Five different lists were available on audio cassette. These were counterbalanced across the five ear conditions and subjects within groups

Results

Hearing thresholds

The results of the hearing threshold (dB SPL) measurements are presented in Table 4 and in Figures 1 and 2. Figure 1 shows the mean hearing threshold as a function of ear condition (UN-unoccluded, M-muff on hard hat, MR-muff/respirator, MG-muff/glasses, and MGR-muff/glasses/respirator) for each of the six groups. The parameter is stimulus frequency. In Figure 2, the data for males and females have been averaged for the normal-hearing young and older and impaired older groups and are plotted as a function of frequency, with ear condition as the parameter. As noted in the table, measurements could not be made at 8 kHz in two of the impaired males with the muff, in one of the impaired males with each of the muff/respirator, muff/glasses, and muff/respirator combinations, in one of the impaired females with the muff, and in two of the impaired females with the muff/respirator combination. In these cases, thresholds exceeded the 95 dB SPL limit of the audio system.

In order to determine the statistical significance of variation in ear condition, stimulus frequency and group on hearing threshold, a nested ANOVA was applied to the data (Daniel, 1983). This analysis showed significant effects of group [$F(5,61)=33.2$; $p<0.0001$], ear condition [$F(4,244)=2167.2$; $p<0.0001$], ear condition by group [$F(20,244)=2.4$; $p<0.001$], frequency [$F(7,427)=77.9$; $p<0.0001$], frequency by group [$F(35,427)=19.1$; $p<0.0001$), ear condition by frequency [$F(28,1708)=110.8$; $p<0.0001$], and ear condition by frequency by group [$F(140,1708)=1393$; $p<0.002$]. Post hoc pairwise comparisons of significant factors using Fisher's LSD test ($p<0.05$) indicated that, averaged across groups and frequencies, hearing thresholds were lowest in the unoccluded condition, followed by the muff/respirator/glasses combination, followed by the muff/respirator and muff/glasses combination which were no different. Thresholds were highest with the muff alone. In the protected ear conditions, mean hearing thresholds in the normal-hearing young and older groups were no greater than 45 dB SPL and 56 dB SPL, respectively. In comparison, thresholds in the hearing-impaired groups were as high as 78 dB SPL.

Sound attenuation

The mean attenuation, derived by subtracting the unoccluded from the protected hearing threshold within subject in each of the four protector conditions, is presented in Table 5 and Figures 3 and 4. In Figure 3, the mean attenuation achieved by each group is plotted as a function of the protector condition, with frequency as the parameter. In Figure 4, the data for males and females within each of the normal young and older and impaired older groups have been averaged. In order to determine the statistical significance of variation in protector condition, frequency and group, a nested ANOVA was applied to the data. The results showed significant effects of group [$F(5,61)=4.3$; $p<0.002$], protector condition [$F(3,183)=104.2$; $p<0.0001$], frequency [$F(7,427)=387.7$; $p<0.0001$], frequency by group [$F(35,427)=1.8$; $p<0.006$], protector condition by group [$F(21,1281)=12.2$; $p<0.0001$], and protector condition by frequency by group [$F(105,1281)=6.8$; $p<0.04$. The protector condition by group interaction was not significant. Post hoc pairwise comparisons indicated

that, collapsed across protector conditions, females achieved 3 dB less attenuation than males. There was no difference due to age or hearing status. Averaged across protector condition, attenuation showed significant increases as frequency increased from 0.25 kHz to 1 kHz and then remained constant, except for a dip at 6.3 kHz. Averaged across groups and frequencies, the least attenuation was achieved with the muff on hard hat in combination with the glasses and respirator and the greatest attenuation was achieved with the muff on hard hat alone. The muff/respirator and muff/glasses combinations fell midway between and were not different from each other. The range in attenuation across these conditions was greatest at 0.25 and 0.5 kHz (9 dB) and least at 2 and 3.15 kHz (3-4 dB).

A comparison of the attenuation achieved with the muffs on hard hat alone by males and females, irrespective of age and hearing status, and the manufacturer's specifications is shown in Table 6. While the values observed in the present study were consistently lower than the manufacturer's specifications, the difference was at most 6 dB across the frequencies and gender groups tested. The range of values was also somewhat greater in the study sample than those reported by the manufacturer. The study standard deviation was 3-5 dB compared with the manufacturer's 2-3 dB.

In order to determine whether head circumference might account for the greater variance, and also male/females differences in attenuation, Pearson correlation coefficients were calculated between head circumference and attenuation for each combination of stimulus frequency and protector condition for the 35 males and 36 females for whom data were available. Significant outcomes are displayed in Table 7. In males, the larger the head size, the greater the attenuation achieved at 3.15 kHz with the muff, muff with respirator, and muff with respirator and glasses. In females, positive correlations between the two outcome measures were observed at 2 kHz for the muff and muff with respirator, and at 1 kHz for the muff with respirator and glasses. However, the values of the correlation coefficients indicated that head size might account for at most 20% of the variance in attenuation.

Consonant discrimination

The results of the FAAF consonant discrimination task are presented in Tables 8 and 9 for the quiet and speech spectrum noise backgrounds, respectively. Outcomes are shown for initial and final consonant contrasts taken separately, as well as the total of the two scores, for each of the five ear conditions. In Figures 5 and 6, results for initial and final consonant contrasts, respectively, are presented for the normal young and older groups and impaired older group, averaged across male and female subgroups. A nested ANOVA applied to these data for the six groups showed significant effects of group [$F(5,66)=45.4$; $p<0.0001$], ear condition [$F(4,264)=27.7$; $p<0.0001$], ear condition by group [$F(20,264)=15.3$; $p<0.0001$], consonant [$F(1,66)=65.8$; $p<0.0001$], background [$F(1,66)=1516.3$; $p<0.0001$], background by group [$F(5,66)=12.3$; $p<0.0001$], ear condition by background [$F(4,264)=3.4$; $p<0.01$], consonant by background [$F(1,66)=21.0$; $p<0.0001$], and consonant by background by group [$F(5,66)=4.2$; $p<0.002$]. Post hoc pairwise comparisons indicated that, averaged across ear conditions, there was no effect of gender. The scores for the two impaired groups were significantly lower than those for the normal groups. For normal-hearing subjects, there was no difference between the unoccluded and protected scores. In contrast, for the hearing-impaired, the protected scores were significantly lower than the unoccluded scores, by 21% in quiet and 25% in noise,

averaged across consonant contrast. Protector combination was not a significant factor. All groups performed more poorly in noise than in quiet. Mean scores declined by 24% for all three groups in the unoccluded condition and by 17% and 27% for the normal and impaired groups respectively in the protected conditions. In quiet, there was no difference between the outcomes for initial and final consonant contrasts. In noise, scores were significantly lower for the final constant contrast, by 8% in the normal groups and 5% in the impaired groups.

Pearson correlation coefficients were calculated between the hearing thresholds observed at each of 0.25, 0.5, 1, 2 and 4 kHz, and each of the four FAAF test scores (IQ-initial consonant in quiet, FQ-final consonant in quiet, IN-initial consonant in noise, and FN-final consonant in noise) within each of the four protector conditions (M, MR, MG and MGR), first for all 72 subjects taken as one group and subsequently for the normal-hearing young and older groups and the impaired older group, averaged across gender subgroups. Figures 7-11 show scatter plots for the 72 subjects for cases where the Pearson correlation coefficients between the two outcome measures were significant at the 0.05 level or better. These were all negative, i.e., the higher the hearing threshold (the greater the hearing loss), the lower the FAAF score. At 2 kHz and 4 kHz, the correlation coefficients were -0.65 or greater, showing that at least 42% of the variance in speech score was accounted for by the hearing threshold. Visual comparison of the slopes of straight line fits to the data for each of the four FAAF scores indicated that these were steeper for consonant contrasts in noise than in quiet, i.e., that a change in threshold had a greater impact on speech understanding in noise than in quiet.

The Pearson correlation coefficients for three groups defined by age and hearing status, taken separately, are shown in Tables 10, 11 and 12, respectively. In these tables significant outcomes ($p<0.05$ or better) are shown for the unoccluded, as well as the for protected conditions. Cases for which the correlation coefficient was -0.65 or greater, are highlighted. This information shows that there were no such instances for the normal younger group (Table 10). For the normal older group (Table 11, the only instance was the relationship between the threshold at 0.25 kHz and the initial consonant score when the muff on hard hat was worn in combination with both the respirator and glasses. Finally, for the impaired group (Table 12), there were four such instances: the 2-kHz threshold and the initial consonant in quiet or noise with the muff/respirator combination, the 1-kHz threshold and the initial and final consonants in quiet with the muff/glasses combination, and the 2-kHz threshold and the final consonant in quiet with the muff/glasses/respirator.

Discussion

The main question for this research was whether the attenuation provided by hearing protective earmuffs attached to a hard hat might be diminished if the device was worn in combination with other protective gear in close proximity. Previous research had demonstrated that if the seal of the muff with outer ear was compromised, the resulting leakage of sound under the ear cup would alter the performance characteristics (Crabtree, 1996; Wagstaff et al., 1996). The magnitude of the change in attenuation had not been investigated nor the impact on signal detection and speech understanding. The devices chosen for the present study included safety glasses and an air purifying half-mask respirator both of which involve placement near the ear.

The results of the study indicated that the wearing of safety glasses and a half-mask respirator in combination with a Class A muff attached to a hard hat did indeed result in a significant decrement in attenuation. The greatest effect was observed when all three devices were worn. This outcome was frequency dependent, with the maximum decrement (9 dB) occurring at 0.25 kHz and 0.5 kHz. Smaller, although still statistically significant, decrements of 4-5 dB were observed in this frequency region with the muff in combination with either of the other devices taken separately. The effect diminished as the stimulus frequency increased.

Hearing status did not influence the degree of attenuation achieved. This outcome was expected since attenuation is derived by subtracting the occluded from the protected hearing threshold at each frequency. Also as expected, in each of the groups sound attenuation was frequency dependent. When the muff on hard hat was worn alone, attenuation increased linearly from 5-15 dB (depending on the protector condition) at 0.25 kHz to 25-35 dB at 1 kHz, remaining fairly constant from 1 kHz to 8 kHz. The statistical analyses showed that women achieved 3 dB less attenuation on average than men. However, for both males and females, the mean real-world attenuation values were within 6 dB of the manufacturer's specifications at each of the eight frequencies tested. Care was taken to achieve an optimal fit of the muff prior to applying the glasses and/or respirator. It must be noted that care was taken to achieve an optimal fit of the muff prior to applying the glasses and/or respirator. In many cases, best fit was achieved at the expense of the fit of the hard hat. Experience suggests that in real-world occupational settings, relatively greater attention would be given to the hard hat, with the likely result that muff attenuation would deviate to a greater extent from the manufacturer's specifications than observed in the present study. In both men and women, head circumference proved to be a determinate of outcome but only at selected frequencies. In men, the larger the head size, the greater the attenuation achieved at 3.15 kHz. In women the effect was observed at 1-2 kHz. We have previously shown that women will achieve less benefit with hearing protective ear plugs that are available in only one size (Abel et al., 1988; Abel et al., 1990). These results underscore the importance of considering personal anatomical variations in selecting hearing protection.

For all groups tested, hearing thresholds were significantly lower in the unoccluded than in any of the protected conditions, and significantly highest when the muffs on hard hat were worn alone. Regardless of the age of subjects or their hearing status, normal or impaired, the greater the sound attenuation afforded by the hearing protector or the protector in combination

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with other gear, the higher the hearing threshold. Averaged across the four groups of normal hearing listeners, protector conditions and stimulus frequencies, protected hearing thresholds ranged from 30-45 dB SPL. Thus, sounds were always comfortably audible. In contrast, for the two groups of hearing-impaired listeners, protected thresholds ranged from 36 dB SPL at 0.25 kHz to 50 dB SPL at 2 kHz to 75 dB SPL at 8 kHz. These results show that in individuals with hearing loss sounds above 2 kHz would have to be relatively loud in order to be just audible. Sounds signifying hazard would have a greater chance of being heard if they were at low frequencies.

Consonant discrimination was significantly poorer in the hearing-impaired than in the normal-hearing listeners. Both groups achieved lower scores in noise than in quiet. Based on the FAAF total score (which included both initial and final consonant contrasts), the difference was 18% for the normal listeners and 26% for the hearing impaired. Although noise was more detrimental for perception of the final consonant, the effect was relatively small at 6% on average. In normal listeners, performance was not affected by the wearing of hearing protection. In contrast, in the hearing-impaired, protected scores were lower by 23%, averaged across quiet and noise backgrounds. This finding is in line with previously published research (Abel et al., 1982; Abel et al., 1993). No differences were observed across the four protector conditions. This was likely because the effect of wearing the safety glasses and half mask respirator in combination was confined to the lowest frequencies tested. These were below the range normally considered important for speech understanding (Schill, 1985). Correlational analyses indicated that for the larger group of 72 subjects, only the high-frequency thresholds (2 kHz and 4 kHz) accounted for more than 40% of the variance in the speech scores within the various protector conditions. This is in line with previous research (Humes and Roberts, 1990, Smoorenburg, 1992). For the hearing-impaired group taken separately, the region from 1-2 kHz appeared to be more relevant for communication capability.

In summary, the results of this study demonstrated that the protection afforded by Class A ear-muffs attached to a standard hard hat for the prevention of noise-induced hearing loss was compromised when the device was worn in combination with other safety gear in close proximity. The decrease in attenuation was greatest at the lowest frequencies tested, i.e., 0.25 kHz and .5 kHz. The fit of the muff itself was also an important determinant of outcome. The attenuation achieved in individuals was related to the circumference of the head. This finding was not gender specific. Fit may also have been compromised by the hard hat attachment. The model chosen, as with most models marketed, did not allow for these two components to be locked into a position that would maximize the protection afforded by each. In order to achieve the maximum sound attenuation, the fit of the hard hat was disregarded. Had the sizing of the hard hat been a priority, the attenuation of the muff would likely have fallen short of the manufacturer's specification to much greater degree than was observed. While the attenuation did not change as a function of hearing status, in individuals with mild to moderate high-tone hearing loss the detection of high-frequency stimuli and speech understanding was negatively affected by the wearing of hearing protectors. Previous studies have suggested that in order to maximize the potential for sound detection, sound localization and speech communication while at the same time minimizing the harmful effects of high level sounds, such individuals should be fitted with either a Class B or level-dependent hearing protector (Abel et al., 1993).

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Recommendations

1. In workplaces where low-frequency sound attenuation is an important consideration, and individuals are obliged to wear other head gear in combination with hearing protectors, it may be advisable to choose ear plugs instead of muffs. Plugs provide significantly more low-frequency attenuation than muffs and may be fitted without regard to other safety gear worn in close proximity.

2. Special attention must be paid to the sizing of all protective gear worn. In cases where hearing protective muffs and a hard hat are components of a single unit, it must be recognized that optimizing the fit of either device may preclude best fit of the other.

3. In users with pre-existing hearing loss, it is advisable to choose a Class B protector in order to optimize the detection of warning signals and communication capability, while at the same time protecting against further noise damage.

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Annex A: Figures

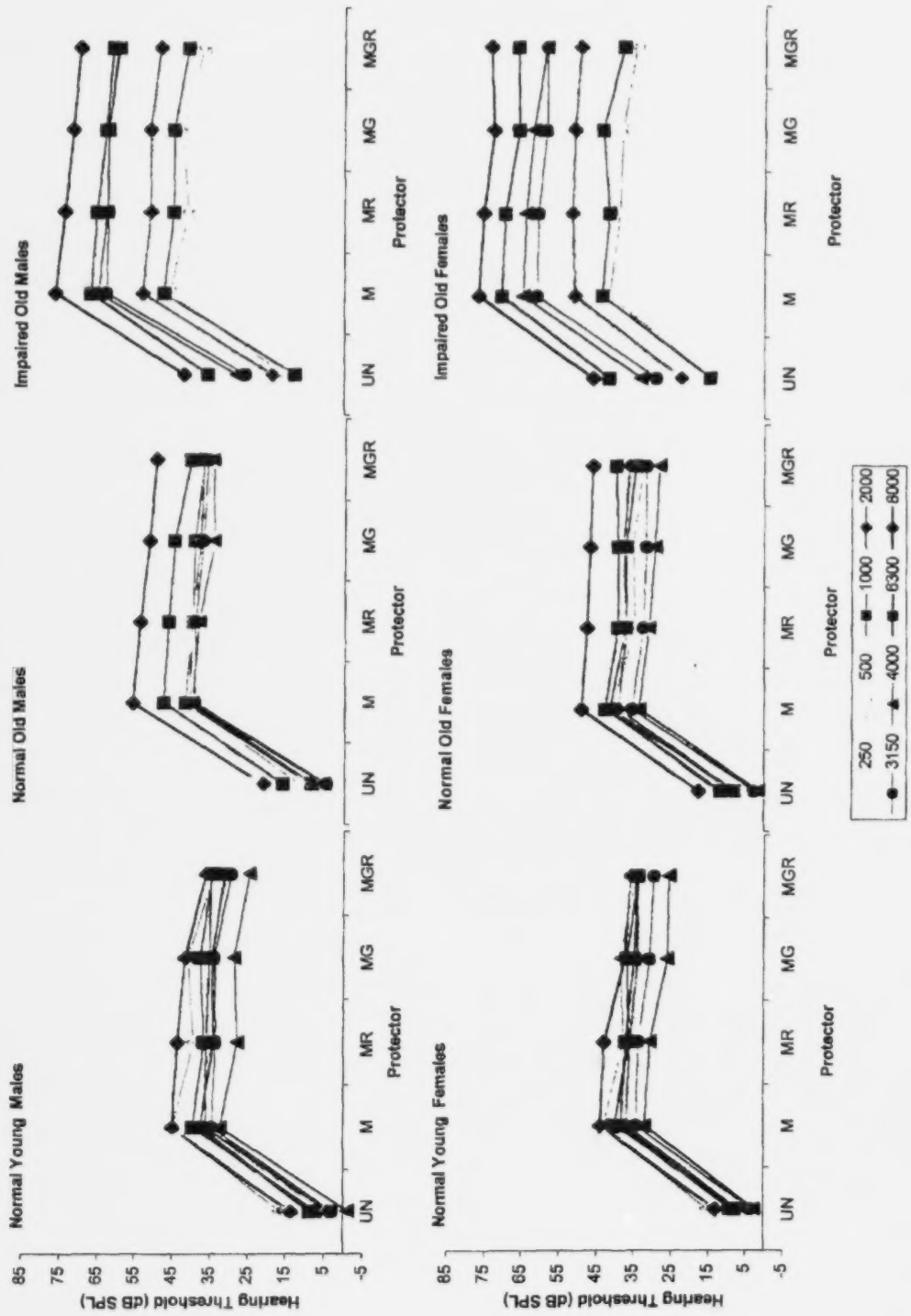

Fig. 1 Hearing Threshold as a Function of Ear Condition: Effects of Stimulus Frequency, Hearing Status, Age, and Gender

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Fig. 2 Hearing Threshold as a Function of Stimulus Frequency: Effects of Ear Condition, Hearing Status and Age

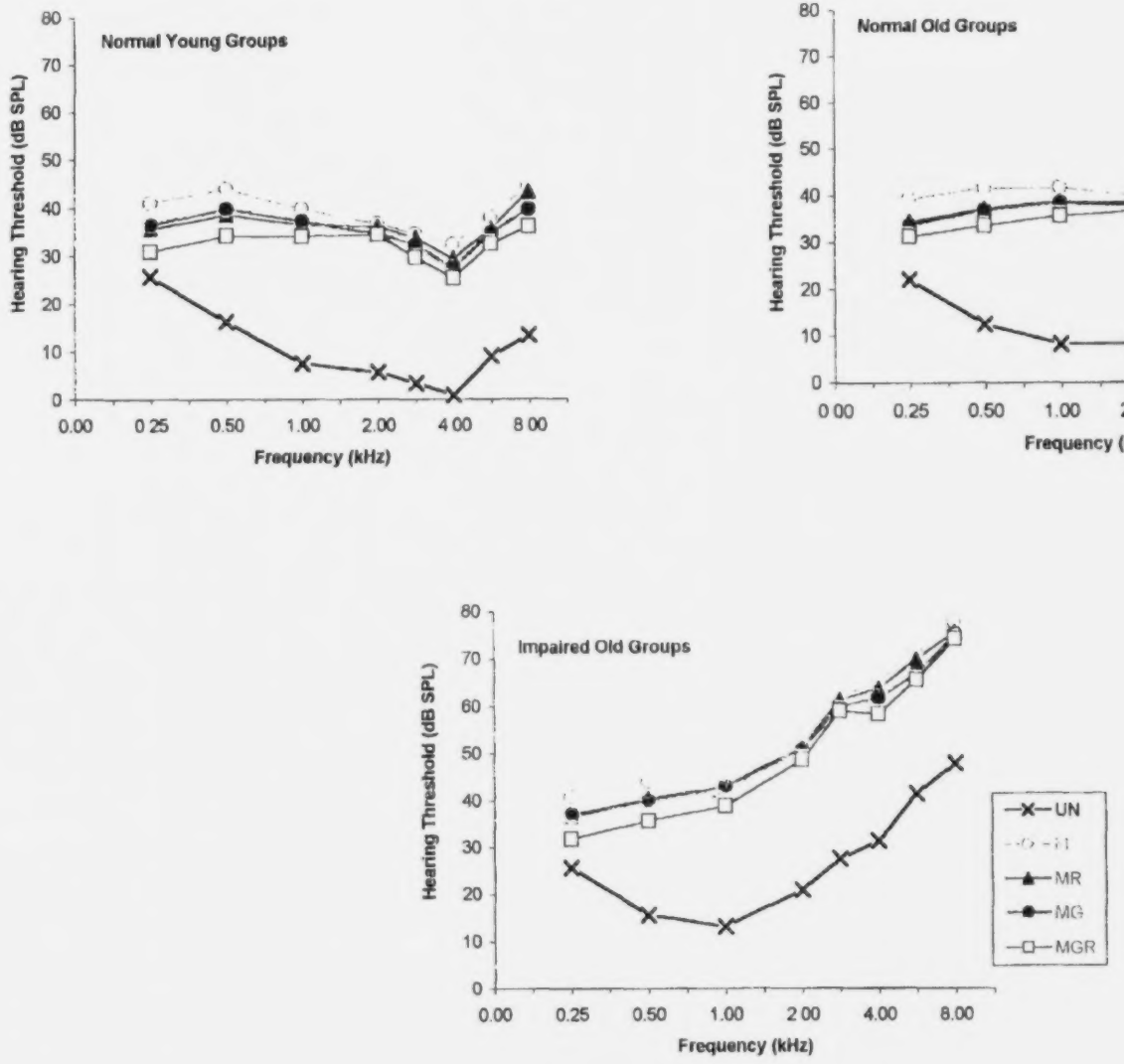

Fig. 3 Attenuation as a Function of Ear Condition : Effects of Stimulus Frequency, Hearing Status, Age, and Gender

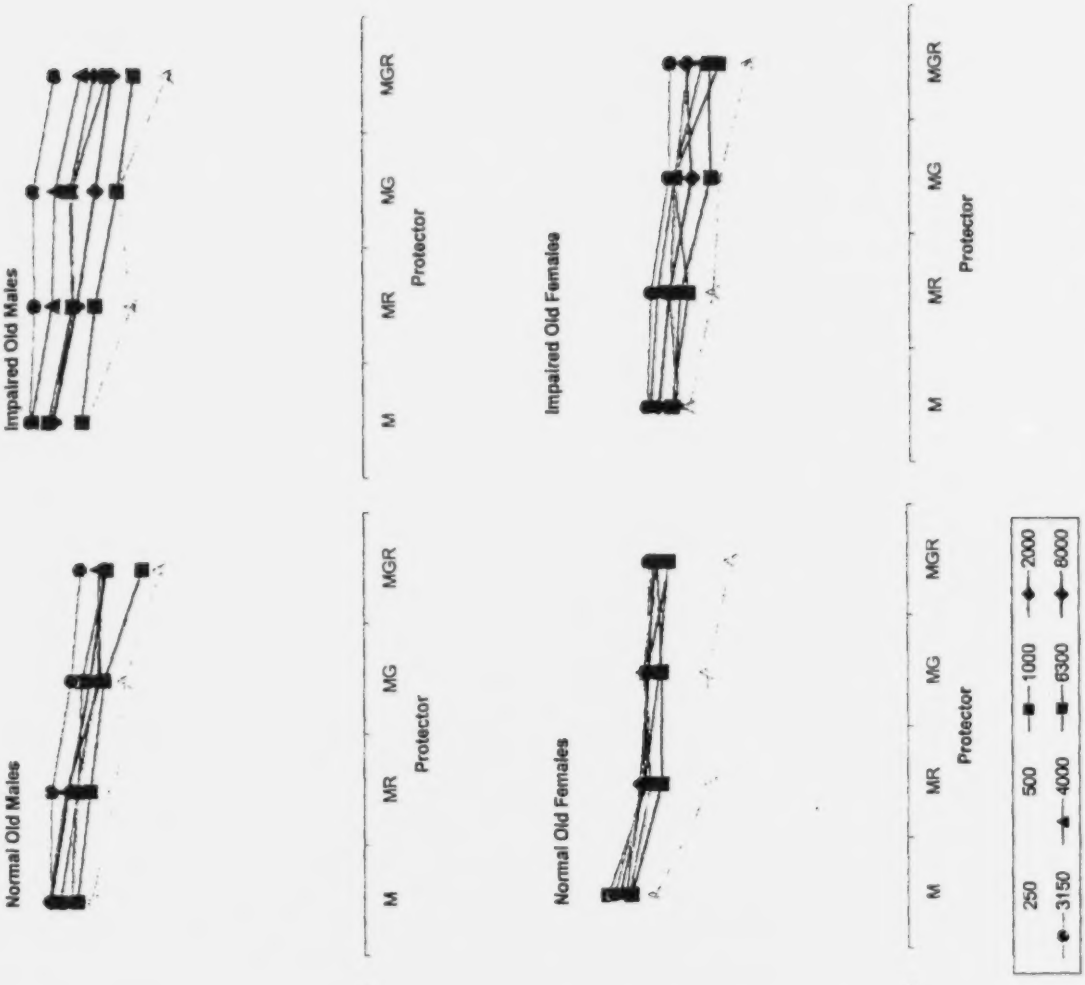

Fig. 4 Attenuation as a Function of Stimulus Frequency: Effects of Ear Condition, Hearing Status and Age

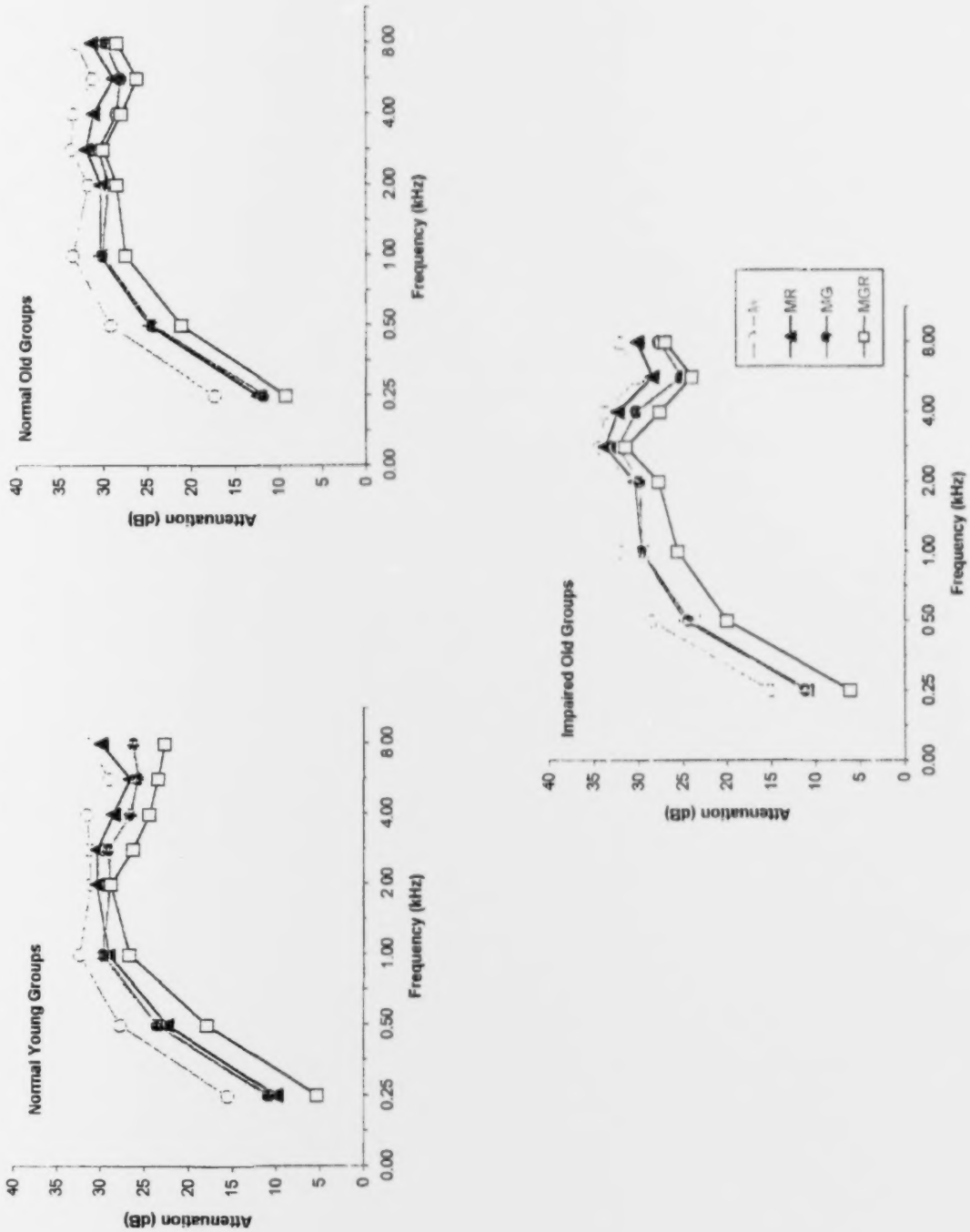

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Fig. 5 Initial Consonant Discrimination as a Function of Background: Effects of Hearing Status and Age

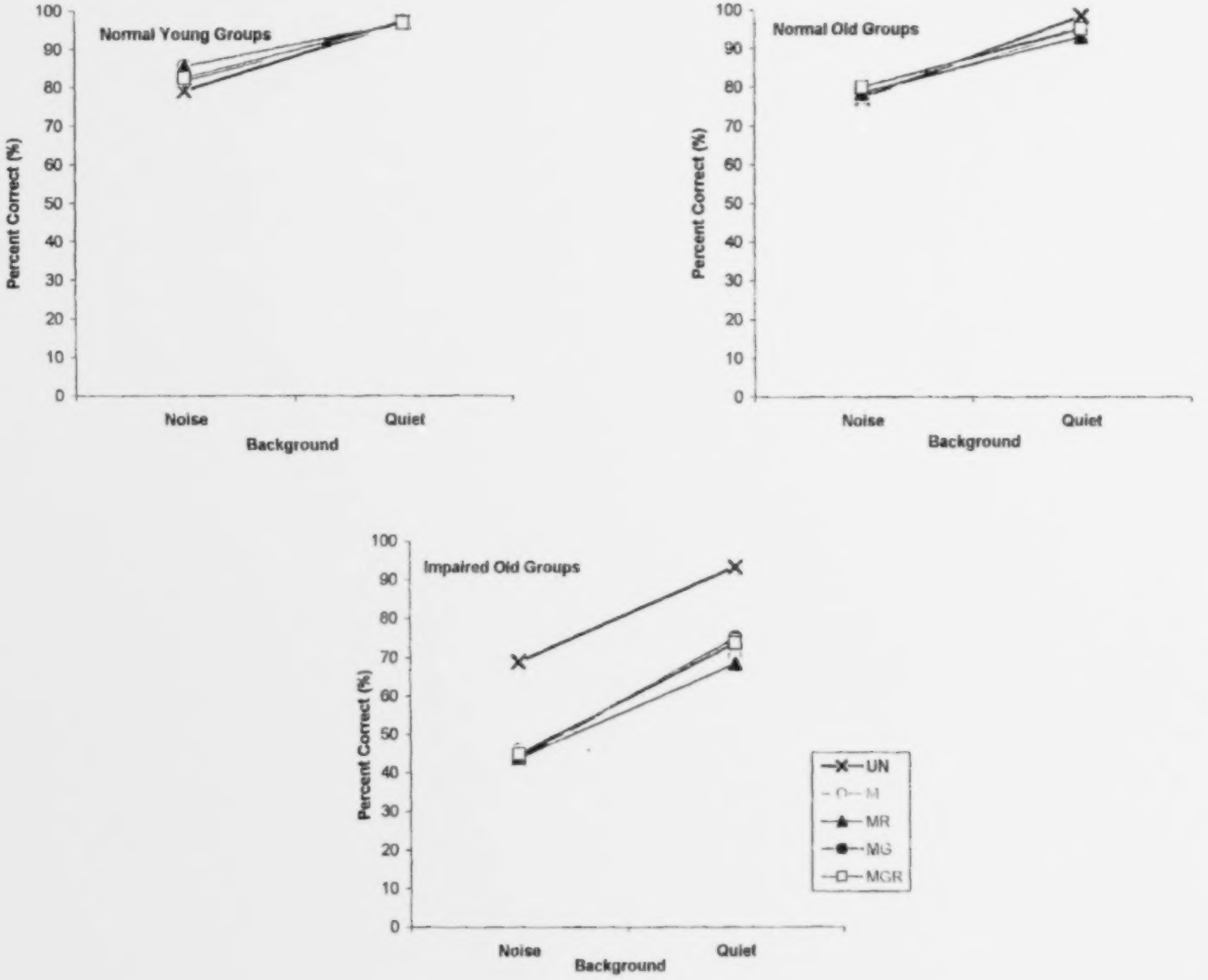

Fig. 6 Final Consonant Discrimination as a Function of Background: Effects of Hearing Status and Age

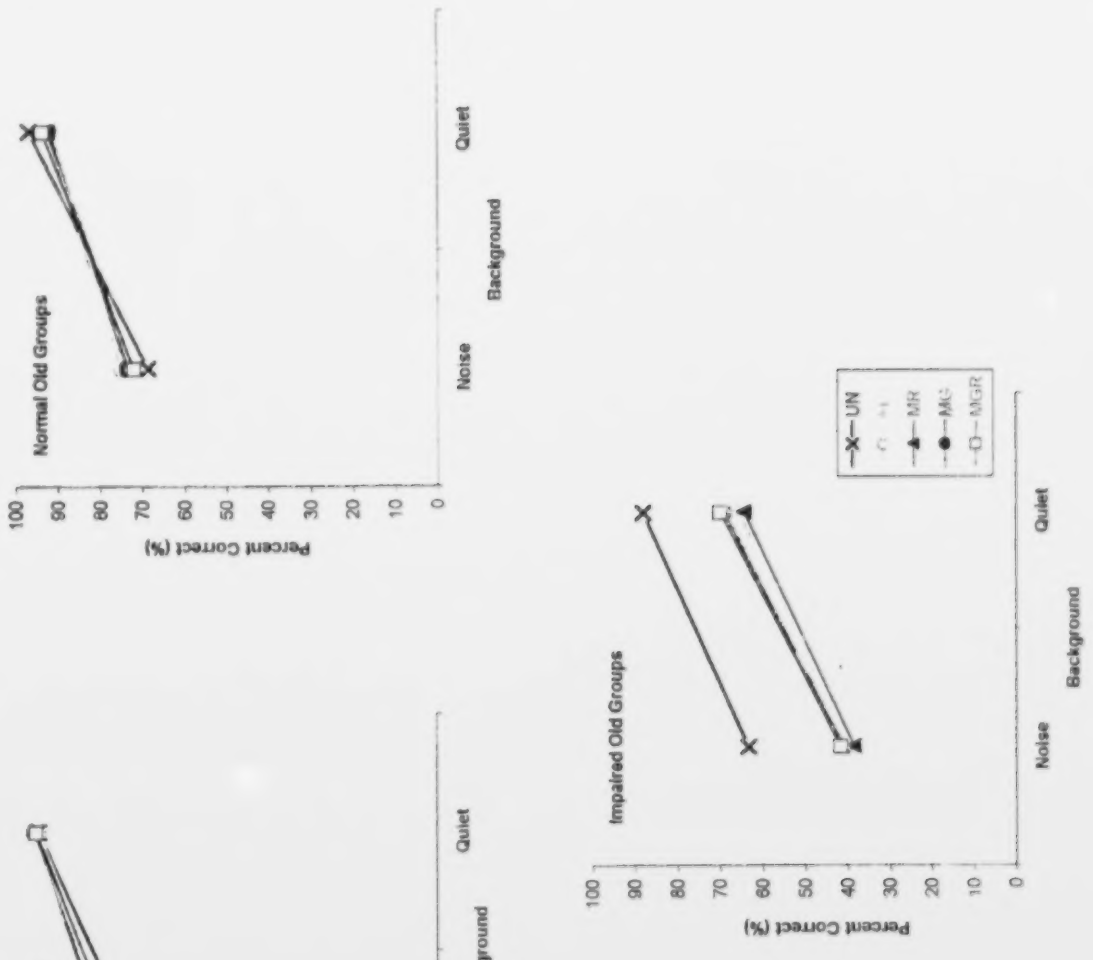

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Fig. 7 Relationship Between Hearing Threshold at 0.25 kHz and FAAF Score by Protector Condition (N = 72)

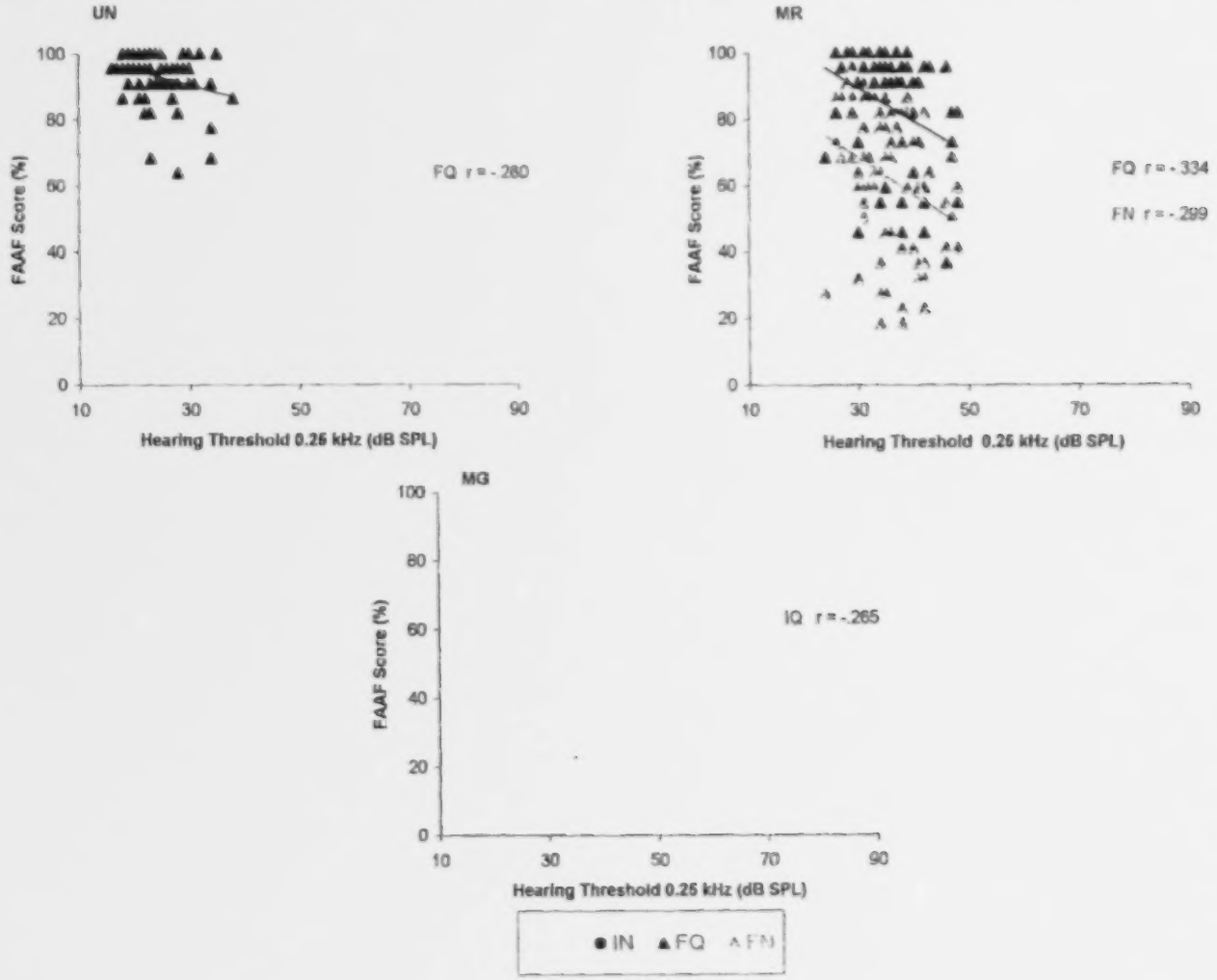

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Fig. 8 Relationship Between Hearing Threshold at 0.5 kHz and FAAF Score by Protector Condition (N = 72)

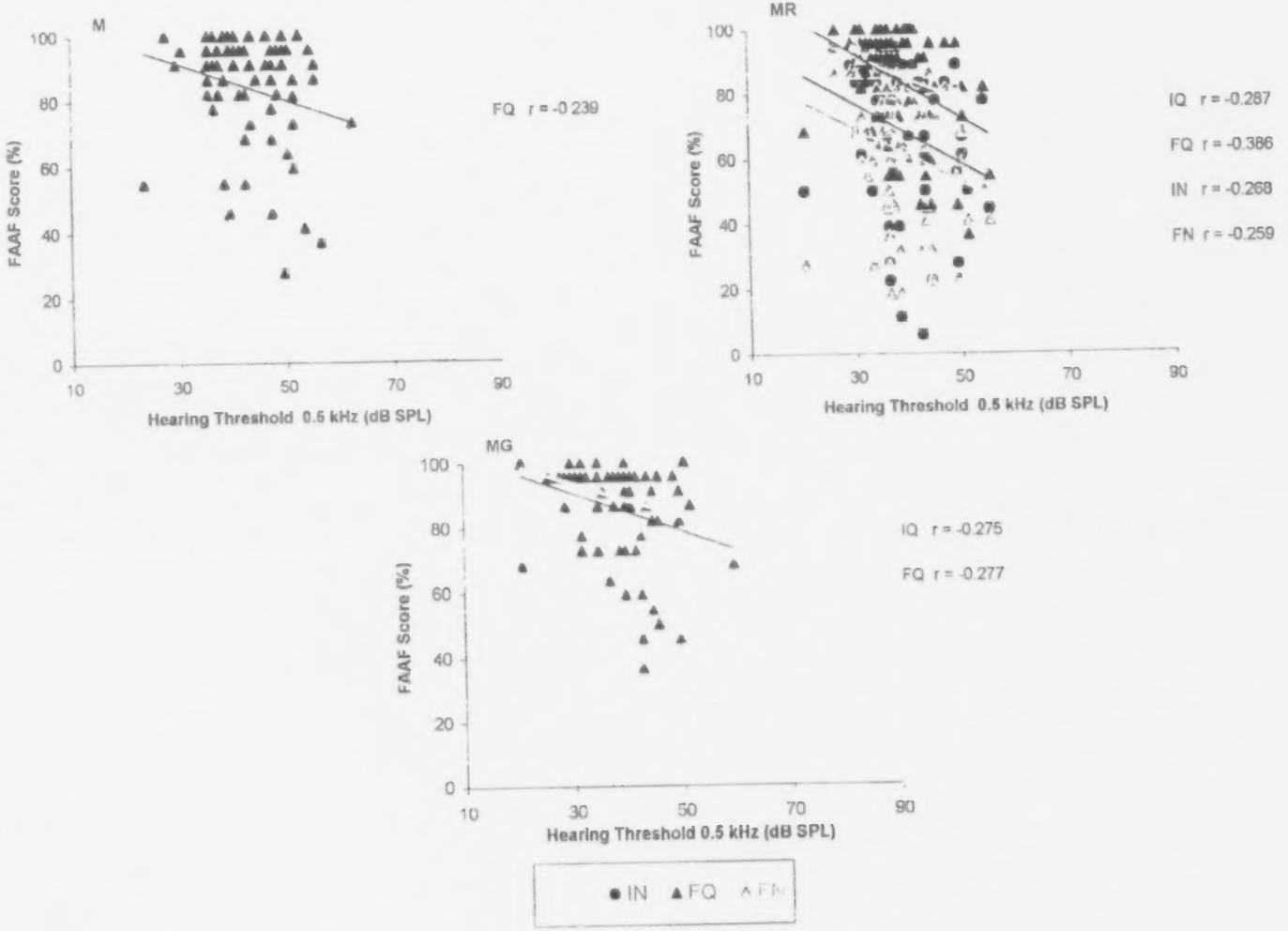

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Fig. 9 Relationship Between Hearing Threshold at 1 kHz and FAAF Score by Protector Condition (N = 72)

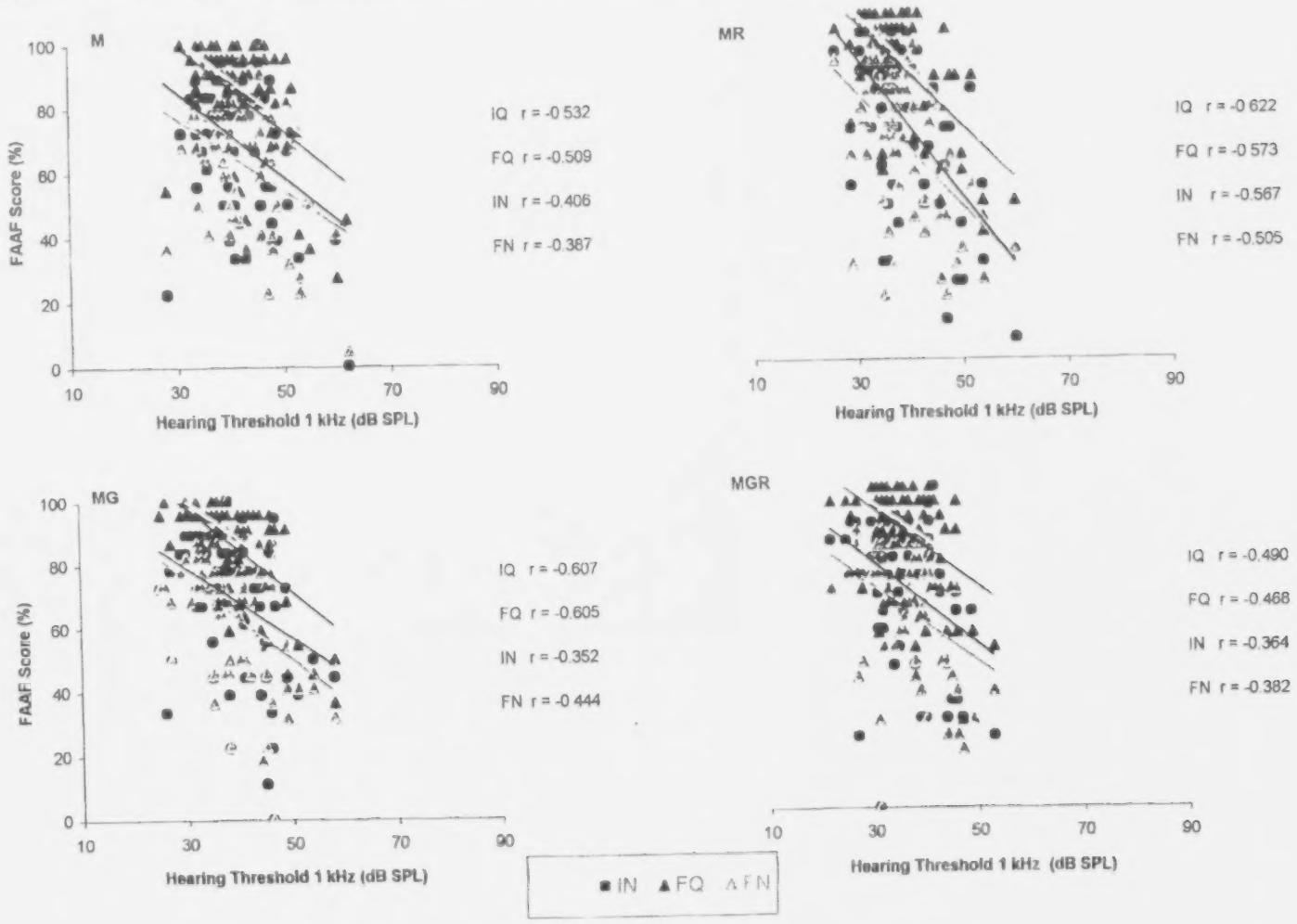

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Fig. 10 Relationship Between Hearing Threshold at 2 kHz and FAAF Score by Protector Condition (N = 72)

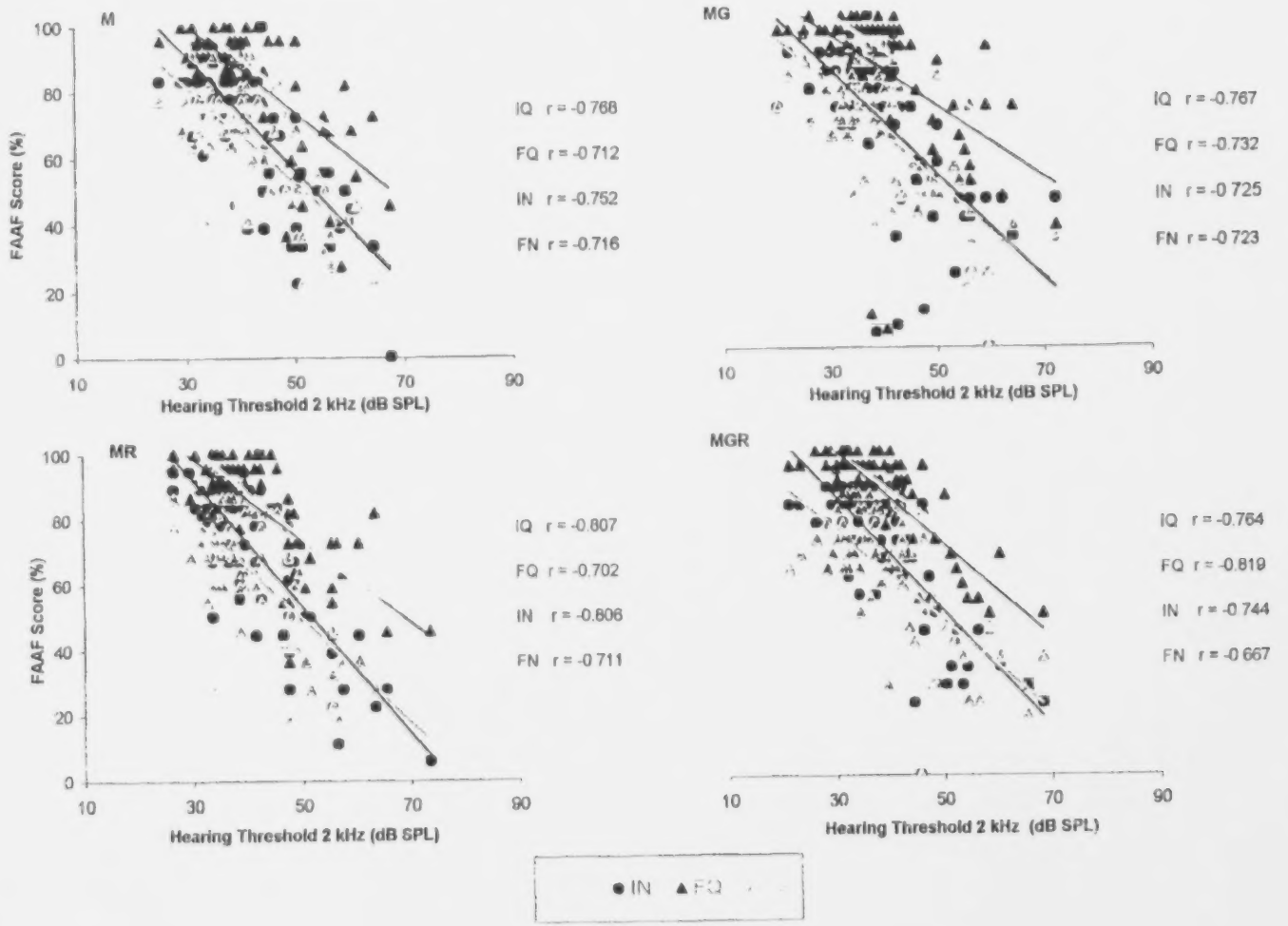

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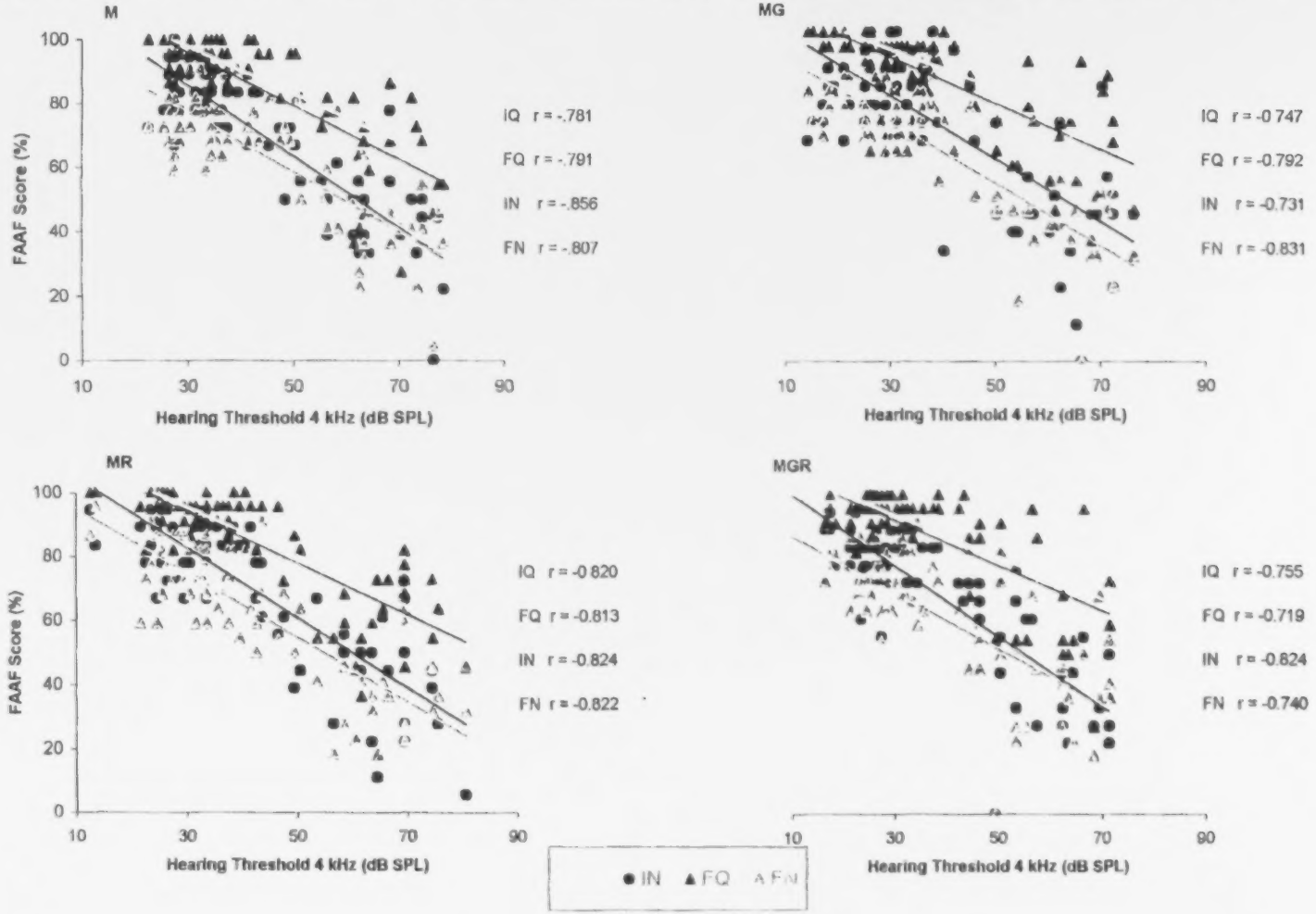
Fig. 11 Relationship Between Hearing Threshold at 4 kHz and FAAF Score by Protector Condition (N = 72)



Annex B: Tables

Table 1. Age by group.

Group	N	Age (yrs.) Mean	SD	Min	Max
Normal Hearing					
Young Males	12	26.4	6.7	19	38
Young Females	12	26.1	6.7	19	38
Older Males	12	54.1	7.7	43	67
Older Females	12	46.7	5.3	40	54
Impaired Hearing					
Older Males	12	55.1	8.6	42	68
Older Females	12	58.9	5.9	49	68

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Table 2. Hearing thresholds (dB HL) by ear for the four older groups.

Freq. (kHz)	Ear	Normal Males (N=11)*	Normal Females (N=11)*	Impaired Males (N=12)	Impaired Females (N=12)
0.5	R	9.2(6.8)[a]	4.8(7.1)	13.8(8.3)	11.5(7.4)
	L	7.8(7.7)	3.6(6.3)	14.4(8.9)	9.9(6.2)
4.0	R	11.8(4.7)	4.0(8.0)	40.2(8.3)	38.8(9.4)
	L	14.0(7.0)	5.3(6.2)	44.4(8.5)	40.1(10.5)

[a]Mean(SD)
*Measurement unavailable in one subject.

Table 3. Head circumference by group.

		Head Circumference (cm.)			
Group	N	Mean	SD	Min	Max
Normal Hearing					
Young Males	12	56.5	1.4	54	59
Young Females	12	57.1	1.3	55	59
Older Males	11*	59.0	1.9	55	62
Older Females	12	56.2	2.2	53	61
Impaired Hearing					
Older Males	12	59.3	2.1	55	62
Older Females	12	55.5	2.0	53	61

*Measurement unavailable for one subject.

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Table 4. Hearing thresholds (dB SPL) by group, ear condition and stimulus frequency.

Group	Freq. (kHz)	Ear Condition UN	M	MR	MG	MGR
Normal Hearing						
Young Males	0.25	24.8(3.8)[a]	41.8(6.1)	35.7(4.8)	37.4(7.0)	30.5(6.8)
	0.5	16.6(5.8)	44.8(7.4)	39.4(6.4)	40.8(7.8)	33.9(9.1)
	1.0	7.1(4.0)	39.5(3.5)	36.5(4.4)	37.5(5.3)	34.3(6.6)
	2.0	4.0(4.5)	36.3(5.7)	35.9(5.9)	35.1(5.7)	34.7(5.3)
	3.15	2.8(4.1)	34.6(4.3)	33.5(5.6)	33.8(7.6)	29.3(5.1)
	4.0	-1.3(4.0)	32.3(4.3)	27.8(6.2)	28.6(6.6)	24.6(6.5)
	6.3	8.8(2.7)	37.5(4.7)	34.0(5.7)	34.4(7.2)	31.0(7.2)
	8.0	13.6(3.9)	45.1(5.5)	43.5(4.2)	41.5(7.1)	36.0(6.3)
Young Females	0.25	26.3(4.6)	40.2(3.6)	35.3(4.8)	35.3(5.6)	31.1(4.3)
	0.5	15.8(4.4)	42.9(4.4)	37.6(3.6)	38.5(5.6)	34.2(4.7)
	1.0	7.8(4.7)	39.9(4.5)	36.2(4.2)	36.7(5.0)	33.8(4.6)
	2.0	7.3(3.5)	37.0(4.8)	35.9(3.8)	33.8(5.6)	34.0(3.7)
	3.15	3.8(3.7)	34.3(5.6)	33.7(4.9)	30.8(5.0)	29.7(4.5)
	4.0	2.8(4.5)	32.1(6.0)	30.6(6.0)	25.9(7.6)	25.6(6.3)
	6.3	9.2(4.5)	38.3(5.6)	37.1(4.9)	34.8(5.2)	33.7(5.8)
	8.0	13.0(5.3)	43.8(5.8)	42.8(5.1)	37.4(6.7)	35.8(6.1)
Older Males	0.25	22.4(5.1)	40.5(7.3)	37.3(6.5)	35.3(6.2)	32.6(6.6)
	0.5	12.0(5.9)	42.2(7.7)	39.5(6.8)	38.4(6.9)	34.5(5.9)
	1.0	8.4(3.6)	42.0(5.0)	39.9(4.3)	39.6(3.9)	36.8(3.3)
	2.0	8.3(5.9)	40.7(6.2)	40.2(4.9)	37.8(6.7)	37.2(6.7)
	3.15	4.8(5.0)	39.4(6.1)	39.3(5.4)	37.1(5.1)	36.0(5.5)
	4.0	5.3(5.5)	40.1(6.7)	38.2(5.6)	34.3(5.8)	34.6(6.7)
	6.3	16.1(5.6)	47.8(6.4)	46.3(5.5)	44.8(8.2)	40.5(8.8)
	8.0	21.2(10.0)	55.8(9.9)	53.8(10.0)	51.4(11.8)	49.7(11.1)
Older Females	0.25	21.8(3.0)	38.3(6.5)	31.7(5.5)	32.1(6.1)	29.8(4.3)
	0.5	12.9(4.8)	41.1(7.4)	34.9(7.1)	35.4(6.8)	32.7(5.6)
	1.0	8.1(4.2)	41.6(6.6)	37.2(6.0)	37.3(7.7)	34.7(5.9)
	2.0	8.3(2.9)	39.4(3.6)	37.0(4.4)	37.8(4.7)	36.3(5.3)
	3.15	2.9(3.3)	35.8(6.1)	32.5(8.4)	31.8(7.8)	31.8(6.3)
	4.0	1.6(4.3)	33.8(6.4)	31.0(9.1)	29.4(8.7)	28.3(6.7)
	6.3	11.9(4.3)	42.8(6.7)	39.4(8.4)	39.4(7.5)	39.9(5.9)
	8.0	17.8(5.6)	49.3(7.9)	47.8(9.8)	46.8(8.8)	46.3(7.2)

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Table 4 (cont'd)

Impaired Hearing

Older Males	0.25	26.5(6.4)	43.3(6.4)	37.8(6.0)	39.1(7.0)	34.2(5.9)
	0.5	16.2(6.7)	46.0(8.0)	41.2(7.1)	42.4(6.9)	37.3(7.0)
	1.0	12.8(6.4)	47.1(5.5)	43.8(7.0)	43.9(6.6)	40.6(6.2)
	2.0	19.7(9.4)	53.0(8.3)	51.0(7.5)	50.9(9.9)	48.3(8.3)
	3.15	27.0(12.9)	63.3(12.5)	62.5(12.6)	62.4(13.1)	60.5(12.8)
	4.0	30.6(10.8)	66.3(9.8)	64.3(10.8)	63.3(11.0)	59.7(10.7)
	6.3	39.7(13.8)	70.5(12.4)	68.7(13.1)	66.0(12.0)	63.7(11.7)
	8.0	46.3(15.5)	76.6(14.1)*	75.2(13.5)*	73.4(14.3)*	71.7(15.2)*
Older Females	0.25	24.8(3.4)	38.2(7.4)	35.2(5.1)	34.5(6.8)	29.2(4.9)
	0.5	14.9(5.3)	42.1(8.1)	39.2(7.4)	37.2(8.7)	33.7(7.2)
	1.0	13.5(7.8)	43.2(9.9)	41.5(8.7)	41.6(10.1)	36.8(8.0)
	2.0	21.9(10.5)	50.5(8.8)	51.3(11.4)	50.2(10.2)	48.8(10.4)
	3.15	27.9(9.1)	60.1(9.3)	59.8(8.6)	57.0(9.1)	57.1(8.6)
	4.0	31.9(10.0)	63.6(8.5)	62.8(8.7)	59.5(9.6)	56.8(8.9)
	6.3	43.0(9.8)	72.1(10.3)	70.8(11.1)	66.9(9.5)	66.8(10.6)
	8.0	49.4(13.2)	78.1(12.0)*	75.5(12.9)*	75.8(13.2)	76.2(12.5)

[a]Mean(SD)
*N=10; *N=11

Table 5. Attenuation (dB) by group, ear condition and stimulus frequency.

Group	Freq. (kHz)	Ear Condition M	MR	MG	MGR
Normal Hearing					
Young Males	0.25	17.1(3.8)[a]	10.9(3.3)	12.7(5.4)	5.8(4.6)
	0.5	28.3(4.3)	22.8(5.2)	24.3(6.3)	17.3(5.6)
	1.0	32.4(4.3)	29.4(5.6)	30.4(7.1)	27.2(7.2)
	2.0	32.3(4.2)	31.9(4.5)	31.1(3.9)	30.7(4.1)
	3.15	31.8(2.5)	30.7(3.9)	31.0(5.5)	26.5(4.8)
	4.0	33.6(3.7)	29.0(4.6)	29.8(6.8)	25.8(7.1)
	6.3	28.7(3.3)	25.2(4.7)	25.6(5.8)	22.2(5.0)
	8.0	31.5(4.9)	29.9(4.3)	27.9(6.1)	22.4(6.8)
Young Females	0.25	13.8(2.8)	8.9(3.7)	8.9(4.3)	4.8(3.0)
	0.5	27.1(4.7)	21.8(3.1)	22.7(5.9)	18.3(3.7)
	1.0	32.2(4.0)	28.4(2.4)	28.9(4.9)	26.0(3.4)
	2.0	29.8(3.7)	28.7(3.6)	26.6(6.9)	26.8(4.3)
	3.15	30.5(4.2)	29.8(2.8)	26.9(4.9)	25.8(4.7)
	4.0	29.3(3.1)	27.8(2.6)	23.2(5.8)	22.8(4.7)
	6.3	29.2(2.8)	27.9(2.2)	25.7(4.0)	24.5(4.4)
	8.0	30.8(3.6)	29.8(3.7)	24.4(6.4)	22.8(5.3)
Older Males	0.25	18.1(3.6)	14.8(3.1)	12.9(3.2)	10.2(5.0)
	0.5	30.2(4.3)	27.5(4.2)	26.4(5.4)	22.5(5.1)
	1.0	33.6(3.9)	31.5(3.0)	31.2(3.2)	28.4(2.9)
	2.0	32.3(5.6)	31.8(5.5)	29.4(4.5)	28.8(5.0)
	3.15	34.7(5.1)	34.5(5.8)	32.3(5.2)	31.3(6.2)
	4.0	34.8(4.0)	32.9(3.8)	29.1(4.9)	29.3(5.9)
	6.3	31.7(3.7)	30.3(3.4)	28.7(3.7)	24.4(6.0)
	8.0	34.7(3.4)	32.7(4.0)	30.3(5.4)	28.5(3.7)
Older Females	0.25	16.6(5.4)	9.9(3.2)	10.3(5.2)	8.1(2.6)
	0.5	28.2(6.4)	22.0(3.5)	22.5(6.0)	19.8(3.0)
	1.0	33.5(4.9)	29.1(3.4)	29.2(5.5)	26.6(4.2)
	2.0	31.2(3.2)	28.8(4.6)	29.5(3.8)	28.1(4.6)
	3.15	32.8(4.0)	29.6(6.4)	28.9(6.6)	28.9(4.4)
	4.0	32.2(4.1)	29.4(6.2)	27.8(6.5)	26.8(3.8)
	6.3	30.8(4.0)	27.5(6.7)	27.5(5.5)	28.0(3.5)
	8.0	31.5(6.7)	30.0(7.2)	29.1(8.1)	28.5(6.3)

Table 5 (cont'd)

Impaired Hearing					
Older Males	0.25	16.8(3.3)	11.3(3.8)	12.6(6.5)	7.7(3.8)
	0.5	29.8(3.2)	25.0(3.2)	26.3(4.3)	21.2(2.7)
	1.0	34.3(3.5)	31.1(4.9)	31.2(5.2)	27.8(3.0)
	2.0	33.3(4.1)	31.3(4.5)	31.3(4.5)	28.6(3.3)
	3.15	36.3(4.0)	35.5(4.3)	35.4(5.1)	33.5(4.3)
	4.0	35.7(2.4)	33.7(3.7)	32.8(4.8)	30.5(5.0)
	6.3	30.8(2.4)	29.0(2.3)	26.3(5.3)	24.0(3.5)
	8.0	33.6(3.0)*	30.7(2.9)*	28.9(5.4)*	27.2(4.3)*
Older Females	0.25	13.4(5.5)	10.4(3.5)	9.8(4.6)	4.4(3.1)
	0.5	27.2(5.3)	24.3(3.6)	22.3(5.4)	18.8(4.3)
	1.0	29.7(3.6)	28.0(3.4)	28.1(3.2)	23.3(2.6)
	2.0	28.6(3.4)	29.3(2.9)	28.3(4.7)	26.8(3.9)
	3.15	32.2(4.8)	31.8(3.6)	29.1(4.0)	29.2(2.9)
	4.0	31.7(6.6)	30.8(4.3)	27.6(4.4)	24.8(2.4)
	6.3	29.1(3.3)	27.8(4.1)	23.9(3.5)	23.8(4.1)
	8.0	30.6(4.0)*	29.4(4.1)*	26.3(4.0)	26.8(4.6)

[a]Mean(SD)
*N=10; *N=11

Table 6. A comparison of the attenuation achieved by males and females fitted with Aero Peltor H7P3E muffs mounted on a LR46 hard hat and the manufacturer's specifications.

Freq. (kHz)	Manufacturer's Specification	Males (N=36)	Females (N=36)
0.25	18.8(2.0)[a]	17.3(3.5)	14.6(4.8)
0.5	28.1(3.0)	29.4(4.0)	27.5(5.4)
1.0	36.2(2.1)	33.4(3.9)	31.8(4.4)
2.0	35.6(2.2)	32.6(4.6)	29.8(3.5)
3.15	38.4(2.3)	34.3(4.3)	31.8(4.3)
4.0	35.0(2.1)	34.7(3.5)	31.1(4.9)
6.3	35.5(2.1)	30.4(3.3)	29.7(3.4)
8.0	36.4(2.4)	33.2(4.0)	31.0(4.9)

[a] Mean(SD)

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Table 7. The relationship between head circumference and attenuation within ear condition in males and females.

Group	Ear Condition	Freq. (kHz)	r	p
Males (N=35)	M	3.15	0.39	0.05
	MR	3.15	0.42	0.05
	MGR	3.15	0.38	0.05
Females (N=36)	M	2.0	0.41	0.05
	MR	2.0	0.45	0.01
	MGR	1.0	0.33	0.05

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Table 8. Consonant discrimination in quiet by group, ear condition and consonant contrast.

Group	Conso-nant	Ear condition UN	M	MR	MG	MGR
Normal Hearing						
Young Males	Initial	97.2(3.8)[a]	95.3(3.2)	97.2(2.9)	96.3(5.0)	96.7(2.9)
	Final	94.7(4.3)	92.8(5.3)	96.2(3.3)	94.0(5.3)	95.1(4.9)
	Total	95.8(2.2)	94.0(3.1)	96.7(2.5)	95.0(4.7)	95.8(3.3)
Young Females	Initial	96.7(3.7)	97.2(3.0)	95.8(3.5)	97.7(3.7)	96.3(3.6)
	Final	94.0(6.2)	95.5(4.3)	94.0(5.9)	96.3(1.8)	94.7(6.1)
	Total	95.2(4.2)	96.3(3.3)	94.8(4.3)	96.9(1.6)	95.4(3.2)
Older Males	Initial	98.6(2.5)	94.0(5.5)	89.8(9.7)	94.0(6.0)	93.5(7.4)
	Final	97.0(3.0)	92.8(7.1)	91.3(7.1)	91.7(5.4)	94.3(2.8)
	Total	97.7(1.7)	93.3(5.7)	90.6(7.2)	92.7(5.2)	94.0(4.3)
Older Females	Initial	98.1(2.8)	94.9(2.9)	95.4(4.6)	95.8(4.8)	95.8(4.2)
	Final	96.6(3.9)	91.7(5.8)	93.6(6.6)	92.5(6.5)	93.2(5.3)
	Total	97.3(2.3)	93.1(3.2)	94.4(4.1)	94.0(4.5)	94.4(3.6)
Impaired Hearing						
Older Males	Initial	94.4(6.7)	72.2(17.2)	70.4(14.9)	72.7(16.3)	74.1(14.3)
	Final	89.8(8.9)	67.4(17.5)	63.3(15.2)	68.6(14.4)	72.7(17.3)
	Total	91.9(6.2)	69.6(16.2)	66.5(12.5)	70.4(13.0)	73.3(14.4)
Older Females	Initial	92.1(12.4)	68.5(16.1)	66.2(16.7)	76.9(15.1)	73.2(16.7)
	Final	86.0(11.4)	62.9(17.1)	64.8(12.9)	69.3(18.4)	66.7(19.4)
	Total	88.8(10.8)	65.4(14.8)	65.4(13.4)	72.7(15.1)	69.6(17.5)

[a]Mean(SD)

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Table 9. Consonant discrimination in noise by group, ear condition and consonant contrast.

Group	Conso-nant	Ear condition UN	M	MR	MG	MGR
Normal Hearing						
Young Males	Initial	80.1(11.5)[a]	83.8(7.6)	85.6(8.0)	84.3(9.1)	84.2(11.6)
	Final	70.8(9.6)	73.9(8.3)	80.3(7.4)	74.6(8.6)	72.0(6.1)
	Total	75.0(6.8)	78.3(6.6)	82.7(5.4)	79.0(6.9)	77.5(6.8)
Young Females	Initial	78.2(10.2)	87.0(8.0)	84.7(9.5)	79.2(6.3)	80.1(6.9)
	Final	67.0(11.5)	73.5(10.0)	72.7(9.5)	77.7(8.1)	74.2(7.9)
	Total	72.1(9.2)	79.6(7.3)	78.1(6.9)	78.3(6.3)	76.9(5.9)
Older Males	Initial	74.6(10.1)	73.2(10.3)	75.0(11.2)	78.2(11.2)	79.6(7.6)
	Final	69.7(10.1)	73.1(6.0)	67.4(10.2)	72.4(7.6)	67.8(11.2)
	Total	71.9(8.3)	73.1(4.7)	70.8(8.3)	75.0(6.5)	73.1(7.7)
Older Females	Initial	79.6(7.2)	81.0(8.0)	81.5(10.2)	81.0(9.3)	79.6(9.3)
	Final	67.8(8.6)	76.9(8.3)	76.9(13.8)	74.6(12.0)	76.1(8.3)
	Total	73.1(5.4)	78.8(7.7)	79.0(7.5)	77.5(9.9)	77.7(5.2)
Impaired Hearing						
Older Males	Initial	69.9(11.5)	50.0(16.9)	48.6(20.0)	50.5(17.3)	49.1(16.2)
	Final	65.2(14.0)	45.5(14.4)	41.7(13.1)	39.4(15.7)	44.3(16.8)
	Total	67.5(8.9)	47.5(13.7)	44.8(15.4)	44.4(14.9)	46.5(15.2)
Older Females	Initial	67.6(16.0)	41.7(17.8)	38.9(17.4)	37.5(19.0)	40.3(22.9)
	Final	61.4(10.9)	38.6(14.1)	34.9(13.6)	42.4(17.3)	38.7(18.7)
	Total	64.2(11.7)	40.0(14.1)	36.9(13.3)	40.2(14.9)	39.4(18.5)

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Table 10. The relationship between hearing thresholds at 0.25, 0.5, 1, 2 and 4 kHz and speech understanding, within ear condition for normal-hearing young males and females (N = 24).

Protector Condition	Freq. (kHz)	FAAF Score	r	p
UN	0.25	FQ	-0.44	0.05
	0.5	FQ	-0.51	0.05
	1.0	IQ	-0.53	0.01
M	0.25	IQ	-0.48	0.05
MG	4.0	FQ	-0.55	0.01
MGR	0.5	FQ	-0.44	0.05
	1.0	FQ	-0.43	0.05
	4.0	IQ	-0.64	0.01
		IN	-0.44	0.05

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Table 11. The relationship between hearing thresholds at 0.25, 0.5, 1, 2 and 4 kHz and speech understanding, within ear condition for normal-hearing older males and females (N = 24).

Protector Condition	Freq. (kHz)	FAAF Score	r	p
M	0.25	IQ	-0.49	0.05
		FQ	-0.47	0.05
	2.0	IQ	-0.41	0.05
		IN	-0.46	0.05
	4.0	IN	-0.57	0.01
MR	0.25	IQ	-0.59	0.01
		FQ	-0.58	0.01
		IN	-0.62	0.01
		FN	-0.55	0.01
	0.5	IQ	-0.57	0.01
		FQ	-0.60	0.01
		IN	-0.56	0.01
		FN	-0.58	0.01
	1.0	IQ	-0.57	0.01
		IN	-0.49	0.05
		FN	-0.48	0.05
	2.0	FQ	-0.51	0.05
		IN	-0.48	0.05
	4.0	IQ	-0.51	0.05
		FQ	-0.41	0.05
		IN	-0.58	0.01
		FN	-0.41	0.05
MG	0.25	IQ	-0.49	0.05
	2.0	FQ	-0.41	0.05
	4.0	IQ	-0.44	0.05
		FQ	-0.62	0.01
		FN	-0.46	0.05

Table 11 (cont'd)

MGR	**0.25**	**IQ**	**-0.66[a]**	**0.01**
		IN	-0.45	0.05
	0.5	IQ	-0.58	0.01
		IN	-0.50	0 05
		FN	-0.53	0.01
	1.0	IQ	-0.58	0.01
	2.0	IQ	-0.49	0.05
	4.0	IQ	-0.45	0.05

[a]Cases for which the correlation coefficients were greater than -0.65 are highlighted.

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Table 12. The relationship between hearing thresholds at 0.25, 0.5, 1, 2 and 4 kHz and speech understanding, within ear condition for hearing-impaired older males and females (N = 24).

Protector Condition	Freq. (kHz)	FAAF Score	r	p
UN	1.0	IQ	-0.48	0.05
	2.0	IQ	-0.57	0.01
M	2.0	IQ	-0.62	0.01
		FQ	-0.48	0.05
		IN	-0.57	0.01
		FN	-0.57	0 01
	4.0	FQ	-0.45	0.05
		IN	-0.57	0.01
		FN	-0.52	0.01
MR	0.25	FQ	-0.52	0.01
	0.5	FQ	-0.53	0.01
	1.0	IQ	-0.59	0.01
		FQ	-0.60	0.01
		IN	-0.55	0.01
	2.0	**IQ**	**-0.73[a]**	**0.01**
		IN	**-0.70**	**0.01**
		FN	-0.49	0.05
	4.0	IQ	-0.50	0.05
		IN	-0.47	0.05
MG	0.5	FQ	-0.41	0.05
	1.0	**IQ**	**-0.70**	**0.01**
		FQ	**-0.68**	**0.01**
		FN	-0.49	0.05

Table 12 (cont'd)

	2.0	**IQ**	**-0.69**	**0.01**
		FQ	-0.49	0.05
		IN	-0.53	0.01
		FN	-0.59	0 01
	4.0	IQ	-0.41	0.05
		FN	-0.59	0.01
MGR	**2.0**	IQ	-0.61	0.01
		FQ	**-0.80**	**0.01**
		IN	-0.61	0.01
		FN	-0.51	0.05
	4.0	FQ	-0.44	0.05
		IN	-0.55	0 01

[a]Cases for which the correlation coefficients were greater than -0.65 are highlighted.

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4. AUTHORS

Sharon M. Abel, Andrea Sass-Kortsak, Aneta Kielar

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14 ABSTRACT

(U) This study assessed the effect of other safety gear worn in combination on the attenuation afforded by earmuffs attached to a hard hat.

Seventy-two males and females participated: 24 under the age of 40 years with normal-hearing, and 48 over the age of 40 years, half with normal hearing and half with bilateral high-tone hearing loss. Measurements made with the ears unoccluded, with the muffs alone, and with the muffs in combination with safety glasses, an air-purifying half mask respirator or both glasses and respirator included (1) diffuse field hearing thresholds from 0.25-8 kHz, and (2) consonant discrimination in quiet and in speech spectrum noise. Attenuation was derived by subtracting the unoccluded from the protected threshold.

Muff attenuation was within 6 dB of the manufacturer's specifications but decreased by as much as 5 dB when the glasses or respirator were worn and by 9 dB with both these devices. Males achieved 3 dB higher attenuation than females. Hearing status had no effect. Consonant discrimination was significantly poorer in noise. The impaired performed more poorly when protected but there was no difference due to combination.

The results demonstrated that hearing protector attenuation may be compromised when are safety gear are worn in combination. In individuals with pre-existing hearing loss, the use of hearing protectors may increase communication handicap.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) hearing loss; hearing protection; combined safety gear

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